IMPLEMENTATION OF PROGRAMMABLE AUTOMATION CONTROLLERS – PROMISING PERSPECTIVE FOR INTELLIGENT MANUFACTURING SYSTEMS

Tomasz Żabiński

Rzeszow University of Technology, Department of Computer and Control Engineering

Corresponding author:
Tomasz Żabiński
Rzeszow University of Technology
Department of Computer and Control Engineering
W. Pola 2, 35-959 Rzeszów, Poland
phone: +48 17 8651766
e-mail: tomz@prz-rzeszow.pl

Received: 11 May 2010
Accepted: 8 June 2010

Abstract
The aim of this paper is to show that absence of industrial controllers with appropriate capabilities – in the literature pointed out as the main development-related barrier for industrial deployment of Intelligent Manufacturing Systems (IMS) – is out of date. Trends in factory automation and the concept of Programmable Automation Controllers (PAC), which creates a promising perspective for industrial implementations of IMS, are briefly discussed. The results of a current phase of a project devoted to PAC-based IMS in a medium-size production company are presented. Experiments with an industrial test bed with limited functionality, used in a daily production process for 11 months, are described. Directions of the development of the system are discussed.

Keywords
factory automation, programmable automation controllers, embedded PC, intelligent manufacturing systems.

Introduction

In manufacturing companies nowadays, many significant changes must be done in order to cope with global scale competition, unpredictable markets and constantly growing demands for products customization. Customers have more individualistic desires and their expectations of participation in the whole design and production process is constantly growing [1–3]. Exigencies for higher quality and smaller delivery times are also constantly increasing, whereas the size of production batches is decreasing. At the moment, most production systems are characterized by centralized solutions in organizational structure as well as in the field of computer and automation systems. These solutions are no longer appropriate, as they are adapted to high volume, low variety and low flexibility production processes. In order to fulfill current market demands, enterprises should reduce batch sizes, delivery times, and product lifecycles but at the same time they are forced to increase product variety and decrease product prices. In traditional centralized manufacturing systems this would create an unacceptable decrease in efficiency due to, e.g. high replacements costs. For this reason, the current challenge is to develop innovative, agile and reconfigurable architectures for distributed manufacturing control and monitoring systems that exhibit intelligence, robustness and adaptation to environment changes and disturbances [4]. The new generation of manufacturing systems is referred to as Intelligent Manufacturing System (IMS) [5], which should be able to perform on-line control and monitoring of production process as well as should discover and provide knowledge about manufacturing process, equipment efficiency and condition simultaneously. Among other things, IMS should provide knowledge for reliable management decisions and
should support techniques for production process optimization. It seems clear that industrial adoption of IMS needs new hardware and software solutions in a factory automation field as well as in a structure of computer systems for manufacturing.

In the field of organizational structures for manufacturing, many concepts [1–5] have been proposed in recent years to make IMS a reality. It seems that for practical purposes, the most promising concepts [5] are: holonic (HMS – Holonic Manufacturing System), fractal, and bionic. The detailed descriptions and comparisons of the manufacturing systems concepts can be found in [6, 7]; further references can be found in [3]. In general, it can be stated that a promising organizational structure is a conglomerate of distributed and autonomous units which operate as a set of cooperating entities [7]. It would be impossible to successfully implement new organizational concepts in industry without a suitable distributed control and monitoring hardware and software platforms.

In publications [4–6] and reports [1, 2], an agent-based software is designated as technology for industrial IMS realization, regardless of the chosen organizational paradigm (holonic, fractal, bionic). The integration of HMS and multi-agent software technology is currently presented as the most promising basis for industrial implementations of IMS [5]. The term holon describes a basic unit of organization and has two important characteristics: autonomy and cooperation. In a manufacturing system, a holon can represent a physical or logical activity, e.g. machine, robot, order, machine section, flexible manufacturing system and even a human operator. The holon possesses knowledge about itself and about its environment and has an ability to cooperate with other holons. From this point of view, a manufacturing system is a holarchy, which is defined as a system of holons organized in a dynamical hierarchical structure. Manufacturing system goals are achieved by cooperation between holons, which combine individual skills and knowledge and dynamically create synergetic and effective systems/subsystems. Due to conceptual similarities of HMS and the agent-based paradigm, it seems to be clear that their combination should create promising platform for industrial IMS implementation.

In spite of many agent-based solution benefits (feasibility, robustness, flexibility, reconfigurability, redeployability, etc.) [8], only few industrial and laboratory applications have been developed and reported in literature [4]. Detailed descriptions of known IMS industrial implementations can be found in [4]. Different barriers and reasons for industrial implementations of IMS have been identified in papers [4, 8]. Two main groups of reasons have been defined, i.e. conceptual efficiency in the paradigms and development-related aspects [4]. In the first group, one of the main barriers is related to higher implementation costs of emerging approaches in comparison to well established centralized solutions. In the second group, the one important barrier for real deployment of agent-based control systems on a factory floor has been indicated. Namely, the absence of industrial controllers with capabilities to run software agents directly on the controller in parallel with the low-level Programmable Logic Controller (PLC) or motion control programs [4]. In papers [4, 8] a detailed discussion of additional reasons (guaranties on operational performance, scalability, commercial platforms, engineering education, design methodologies, standards, agent system performance, misapplication) for poor adoption of the IMS by industry can be found.

In the paper, current results of a project devoted to the development of a real industrial test-bed for IMS are presented. The goal of the current project stage is to prove that modern factory controllers can constitute an appropriate hardware and software platform for successful industrial IMS implementation. This stage is also meant to provide valuable benefits for the factory management board; therefore, the present functionality of the system has been limited in comparison with the complete IMS to main practical functions, i.e. monitoring the availability, performance and quality of operation of machines and operators. Additionally, an initial quality control system and necessary PLC control tasks were implemented. Until now, hardware has been selected and a prototype system with limited functionality has been installed in a medium-size screws production factory. The system has been tested in a real production process. So far it has been experimentally proven that the abovementioned main development-related barrier for real deployment of IMS, i.e. absence of industrial controllers with appropriate capabilities, is out-of-date. Within 11 months of the system’s operation, it has been proven that modern Programmable Automation Controllers (PAC) are capable of running data processing, communication and graphical user interface modules directly on the PAC controller in parallel with PLC control programs. The hardware and software system which has been created in the factory constitutes a platform for complete future IMS implementation.

The project has been created by Department of Computer and Control Engineering, Rzeszów University of Technology, in cooperation with the student scientific circle ROBO, Bernacki Industrial Ser-
services company and a screws production company. The project has been created under the auspices of Green Forge Innovation Cluster.

The paper is organized as follows: Section titled “Current trends in factory automation” reviews the current trends in factory automation which are important in the field of IMS industrial implementation. Section titled “Industrial testbed structure” describes a current functionality and structure of the real testbed deployed in the screws production factory. Section titled “Future work” provides information on the five main fields in which the future work is planned to be performed. Section titled “Conclusions” summarizes and concludes the paper.

Current trends in factory automation

On the basis of the author’s observations, reviews of companies’ reports and practical experience gained during the IMS implementation project, as well as on the author’s presence at Hannover Fair in 2010, it could be stated that the main current trend in factory automation is full integration of automation and computer tools, methods and devices.

The most important tendency in the field of hardware is to substitute classical Programmable Logic Controllers (PLC) for Programmable Automation Controllers (PAC – by some vendors called embedded PC controllers) especially those with operating systems like, e.g. Windows CE or Windows XP Embedded. PACs meet the complex demands of modern manufacturing control systems as they combine features of traditional PLC and motion control technologies, distributed control systems, remote terminal units and personal computers. The main feature of PACs is the ability to simultaneously use the same device for various tasks, i.e. discrete control, motion control, and process control; complex PID algorithms; advanced control structures like neural network of fuzzy logic; data collection, e.g. using various inputs types, additional measuring devices or RFID tags; data processing and temporary storage; database communication; remote monitoring; communication using standard computer protocols and technologies (Ethernet, TCP/IP, web services) and to provide graphical user interface. The important feature of PACs is that there is a possibility to use various programming languages, i.e. typical PLC like ST, FBD, IL, SFC, LD (IEC-61131-3) as well as general programming languages like C, C++, C#, Visual Basic, Java, Delphi, etc. Another important feature of PACs is multitasking, which simplifies implementation of complex software solutions. Flexible and modular structure of PACs allows system expansion in accordance with the needs, e.g. the amount and type of inputs and outputs or communication devices can be successively modified.

In software tools for factory automation, there is a tendency to provide one Integrated Development Environment (IDE) for various tasks, i.e. PLC and motion controllers configuration and programming; visualization; general programming, e.g. data processing, graphical user interface or communication; C/C++ programs for real-time operation and control; integration with Rapid Control Prototyping environments like Matlab; condition monitoring; precise measurements; robotics and vision. More importantly, it is relatively easy to perform communication between different software modules which run on PACs. In Beckhoff systems, for example, communication between PLC programs and modules written in C# can be done via direct reading and writing variables in PLC or using notification mechanism and callback functions. The exemplary IDE which is declared to have, in the near future, the whole mentioned above functionality is TwinCAT 3.0 from Beckhoff [9].

The PACs features enumerated above allow the use of PACs not only as devices to machines or processes control, but also as platforms for developing more sophisticated systems, e.g. agent-based ones, which can be used to create IMS.

PACs are becoming more and more popular due to the fact that their prices are currently comparable to traditional PLCs but their functionality differs significantly. PACs which have been used in the project described in section 3 include Windows CE operating system, PLC real-time control subsystem, DVI and USB interfaces for monitor, mouse, keyboard or touchable monitors connection. PLC control programs written in ST language, graphical user interfaces and communication modules written in C# run on the same PACs devices simultaneously with intensive inter-module and database communication.

Industrial testbed structure

The industrial testbed installed on the screws production factory floor level currently includes two machine sections. In each section there is one controller installed and there are six machines for cold forging connected to the controller. The testbed has been included in a daily screws production process in various configurations since 15th of May 2009. Machine operators interact with the prototype system via custom-made Human Machine Interface (HMI) [10]. PACs with Windows CE, which combine
PLC functionality with general programming capabilities, were chosen. An Ethernet network was chosen for communication between controllers and other system parts. For real-time communication between controllers and distributed input-output modules the EtherCAT protocol was chosen. The testbed structure for one machine section is shown in Fig. 1.

At the moment, the software part of the system consists of three layers: a factory floor level software for PACs, data servers and www client stations. Four layers in the software for PACs can be distinguished:

- the PLC program written in the ST language;
- the middleware module written in C# for communication between the PLC program and Windows CE programs;
- the module written in C# for data processing and communication with database and with other system parts;
- HMI written in C#.

The structure of the software for a factory floor level is shown in Fig. 2.

In the data server layer, the PostgreSQL database has been used together with the GlassFish application server and web services written in Java. In the www client stations layer websites written in JSF, JSP, Ajax and JavaScript have been used. Communication inside the system has been performed using web services or EJB technology what simplifies communication in a heterogeneous software environment.

Fig. 1. Testbed structure.

Fig. 2. Structure of the factory floor level software.
Current PLC and HMI software for PACs was implemented in order to connect up to 6 machines to one controller. It provides flexibility in the system structure, e.g. for more demanding PLC or CNC control tasks there is a configuration of one controller for one machine possible. In sections with simple machines or machines already equipped with controllers, it is possible to create a configuration with one PAC controller and up to six machines.

As human operators still play important role in manufacturing systems, intensive effort has been dedicated to creating a proper design of the Human System Interface (HSI) [10] for the testbed. Currently, HSI consists of two main layers, i.e. a www layer and a factory floor layer (HMI). The first layer is a web page accessed through a web browser from the factory intranet or the Internet. The second layer is an HMI application, which runs on PACs installed on the factory floor. In this layer, the communication between an operator and the system is done via a 15” touch screen monitor. The www layer includes two main sections, i.e. an on-line view and statistics. The on-line view enables on-line monitoring of machines operation modes, e.g. production, stoppage, operator’s absence and other information like: operator’s ID, order ID, shift production quantity, machine operation structure or detailed history of events. The on-line view for a machine section with 11 machines is presented in Fig. 3. The tree control in the left panel reflects the factory hierarchical structure. Detailed information presented on the right panel depends on the element chosen in the left panel.

HMI is an application written in C# for .Net CF with two main operation modes, i.e. locked and unlocked. In the locked mode an operator can only observe information presented on the screen but in the unlocked mode an operator can interact with the system. The HMI operation mode can be changed using an operator’s RFID card. In the locked mode, visual information of machines’ current operation modes, production plans and their realization and the necessity of an operator’s interaction with the system are presented. In the unlocked HMI mode, an operator can perform various tasks, e.g. log in, log out, take up a shift, select and confirm an order, input stop reason, input quality control data, etc. The main screens for the locked and unlocked mode for a machine section with six machines are presented in Fig. 4.

Fig. 3. On-line view for a machine section.

Fig. 4. HMI locked (left) and unlocked (right) mode screen for six machines.
At the current development stage, the system is mainly responsible for collecting and processing data concerning the machines’ operation, quality control, production orders completion and operators’ work. The PLC layer is responsible for detecting and registering events which occurred in the machine, for instance, starts and stops, failure and emergency signals, machine operation mode, signals from condition monitoring devices, etc. The PLC program is also responsible for registering the amount of produced pieces. Information about events, including timestamps, machine and operator’s identifiers and other additional parameters, is stored in the database. Every production stoppage must be assigned with an appropriate reason; some, like tool failure, are automatically detected, while others must be manually chosen by operators via HMI.

On the server side there are software modules used for calculations of different Key Performance Indicators (KPI), e.g. production, equipment and operators’ efficiency. Exemplary production quantity report (stated in items) for chosen time period is shown in Fig. 5. During the analyzed period, there were large fluctuations of production quantity, as is shown in Fig. 5. This provided the factory management board a stimulus to examine the reasons for and come up with solutions to this problem.

Additionally, machine operation time structure is analyzed and can be shown in a horizontal graph (Fig. 6). At the moment, there is a possibility to analyze data from three points of view: a general view, a view with stop reasons and a detailed view. The general view divides machine operational time into three categories, i.e. the operator’s absence, the automatic production and the stoppage. In the analysis for the view with stop reasons, each stoppage time period is associated with the appropriate stop reason. In the detailed view, periods of the manual machine operation are distinguished in each stoppage time. Different colors are designated to appropriate time intervals (Fig. 6), e.g. the stoppage – light brown, the automatic production – light green, the electrical breakdown – red, etc. There are many more statistics and KPI reports available in the system.

Fig. 5. Production quantity report – number of produced items as a function of days.

Fig. 6. Machine operation structure – general view and detailed view.
Within 11 months of the system operation, 355402 main events were registered in one machine. It seems clear that manual analysis of the data, even for a system with only one machine, would be extremely difficult. Therefore, there is a need to employ artificial intelligence and data mining technology to give the factory management reliable knowledge of the production process. The necessity to use artificial intelligence in various manufacturing systems areas is frequently reported in literature.

As a result of the long term test, while the system has been included in regular daily production, it can be stated that the selected hardware and software platform constitutes a promising structure for industrial implementation of the IMS, as the software modules (HSI, communication, data processing and acquisition) for Windows CE have been running successfully on the embedded PC controller in parallel to PLC programs.

### Future work

There are five main fields in which the future work is planned to be performed in parallel, i.e. industrial testbed development; condition monitoring subsystem development and integration with the existing system structure; data mining and artificial intelligence support; Petri Nets based manufacturing system modeling and production process scheduling; and multi-agent software development.

The first field deals with the industrial testbed development. It is planned to include additional 58 machines in the system and to install next 18 PACs with additional 45 EtherCAT communication modules for distributed data collecting. It is planned to continue the development of HSI and to apply vision sensors for monitoring and analysis of machine operators’ behavior.

In the second field, an additional diagnostics and process monitoring equipment will be included in the system, e.g. current and vibration sensors, etc. It is planned to use Support Vector Machines method for condition monitoring of cold forging machines in the factory.

The third field concerns the development of data mining and artificial intelligence software modules for supporting the management and control of the manufacturing system. So far the research has been devoted to automatic patterns (rules) generation to discover connections between values in the database. Initially the patterns will be used for detecting operators’ actions which could decrease machines and production process efficiency, e.g. increasing downtime duration and number of breakdowns. Obtained rules should give an answer to questions like, e.g. what factors and in what manner influence production process, under what circumstances problems occur, how operators react to diagnostic messages, etc. It is also possible to use the rules for planning operators and machines assignment to exact production tasks in order to minimize the number of failures and maximize production efficiency. On the basis of historical data, the system should automatically detect the possibility of problem occurrence and suggest the best solution (e.g. task allocation) to reduce the probability of the stoppages. In order to employ data mining techniques like classification and association rules, decision trees, etc. it is necessary to consider an appropriate attributes selection; data preparation (cleaning, normalization, grouping, etc.); a data mining models selection and their reduction and interpretation. It is planned to employ Waikato Environment for Knowledge Analysis (WEKA) to develop the data preprocessing workflow and to build mining models. WEKA is a popular suite of a machine learning software written in Java and available under the GNU General Public License. For model reduction, the automated query generation method is considered.

The fourth field concerns Petri Nets based manufacturing system modeling and production process scheduling. The model is represented in the form of Hierarchical Timed Coloured Petri Net. A scheduling method is based on production process model and is adequate to Flexible Job Shop problem and takes into consideration setup times, transportation times, release time restrictions, batch processing as well as preemption of tasks [11]. The fully automated Petri Net based module for generating and simulating the production process in the screws production factory is under development. It is planned that the scheduling module will obtain data from the monitoring system in real time and will generate production plans by the model simulation using data mining and artificial intelligence support. The CPN Tools software has been used for developing and testing current module version, the target module will be based on Java technology and will be integrated with the currently developed system.

The fifth field concerns the development of a multi-agent system structure for a holonic-based IMS. The introductory research in the field will be devoted to the analysis of the requirements and to the design system topology. It is planned that two approaches for an agent encapsulation will be combined, i.e. the functional and the physical decomposition. Due to the first decomposition approach agents responsible for system support, process modeling and
task scheduling (contact agent, order agent, supply agent) will be defined [12]. Due to the second approach, agents related to a factory floor equipment, e.g. machine agent, machine section agent, etc. will be used. The possibility of using currently available multi-agents frameworks (e.g. FIPA-OS, April Agent Platform, JADE, Comtec Agent Platform) will also be examined.

Conclusions

Typical current manufacturing systems, due to their centralized and static hierarchical structure, suffer from the lack of flexibility, robustness and reconfigurability. Holonic organizational concept and multi-agent technology have been widely recognized as an appropriate platform for industrial implementation of the next-generation innovative manufacturing systems. New hardware and software solutions in factory automation field, i.e. PAC devices, enable industrial implementations of IMS which are currently extremely rare. In the paper the results of the current stage of the project devoted to IMS implementation in the medium-size screws manufacturing company were presented. The appropriate hardware for the factory floor system level was chosen, the system structure was designed and implemented, the preliminary industrial testbed was constructed, and the limited functionality prototype system was installed and tested in the real screws production process.

In conclusion, it can be stated that PAC devices together with other current trends in factory automation which were enumerated in the paper constitute of a promising hardware and software platform for industrial IMS implementation.

References

[9] infosys.beckhoff.com